
1.1 Focus

Forest inventory is a process for obtaining information on the quality and quantity of forest resources and forms the foundation of forest planning and forest policy. While early concepts of sustainable forest management and forest inventory focused on timber production (Hartig 1795; Cotta 1804), modern forest inventory concepts support a holistic view of forest ecosystems addressing not only timber production but also the multiple functions of forests as well as the need to understand the functioning mechanisms of forest ecosystems (von Gadow et al. 2002; Corona et al. 2003).

Forest resources assessment facilitates a multifaceted analysis and study of forests not only as an important source of subsistence, employment, revenue earnings, and raw materials to a number of industries but also for their vital role in ecological balance, environmental stability, biodiversity conservation, food security, and sustainable development of countries and the entire biosphere. Forests have to be managed judiciously not only for environmental protection and other services but also for various products and industrial raw material. In some parts of the world biological resources are being depleted faster than they can regenerate. Following the 1992 United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro considerable progress has been made in the area of sustainable forest management. Among others, the International Tropical Timber Organization (ITTO) and the Forest Stewardship Council (FSC) developed criteria and indicators for sustainable forest management and certification. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) describes measures to mitigate greenhouse gasses and addresses in Article 3.3 in particular the impact of deforestation and afforestation on global climate change. The Convention on Biological Diversity (CBD) that was ratified in 1994 deals with the protection and maintenance of biodiversity.

Forest resources assessments have their focus on the provision of information, which has several implications:

1. The information provided has to satisfy user needs. An inventory is generally not carried out for the needs of a single stakeholder; multiple issues of forests have to be covered. The objectives must be defined by those who require the data to be collected. All groups of users of inventory results should be involved in this phase of planning. Very often, the number of those interested in the inventory results increases after an inventory has already begun or after the findings have been published, so the data collected usually fail to satisfy all demands for information. Before defining the objectives it is advisable to make an inquiry not only among forest authorities but also among private forest owners, the wood-processing industry, land-use planning and environmental protection agencies, consumers of secondary forest products, wildlife organizations, and other potentially interested parties, thus enabling them to articulate their particular needs for information. In addition, this approach increases the possibility of finding partners who will make a financial contribution.
2. The information obtained by an inventory is typically presented in maps and statistical estimates. The basic concept of any statistical presentation is to summarize the population of interest and extract the facts important for potential users. This is generally done by presenting statistical parameters such as mean values, totals, or ratios and percentages. In addition, information on the variability or diversity of a population is an important ecological issue.
3. The information has to be objective. All parts of the population should be covered by the inventory; no part should be intentionally excluded. Data must be assessed in a nonsubjective way. Objective information requires the objective assessment of data. When information is gathered by some form of sampling, only application of a statistical design with known selection probabilities for any population element can ensure the integrity of the information-gathering process (inventory).
4. The information has to be reliable. The results of any sampling survey are always estimates rather than true values and are thus subject to a certain degree of uncertainty, as only part of the population is assessed. The uncertainty can be reduced through an optimal combination of sampling design and sample size in order to increase the precision of the estimates and to reduce sampling errors. The measurements themselves may be subject to error caused by, for example, inappropriate measurement devices, poor training, or subjective interpretation of measurement rules and definitions. Investments in improved instruments and the provision of intensive

training of field crews usually generate a handsome payback in the form of an increase in the quality and accuracy of data. It is necessary to specify the degree of precision and accuracy (see Chap. 3.4) to which the results should attain. This must be decided by the prospective users, though it is often difficult for administrators to think in terms of sampling error.

5. The information must be assessed in a cost-efficient way. Once forest managers and decision-makers have provided a rough definition of the objectives, several alternative inventory designs should be investigated. Alternatives can be based on different sampling design, sampling intensities, or data sources. Comparison of these alternatives allows assessment of the cost—benefit relationship and the final definition and weighing of the objectives.
6. The results of an inventory should be intuitively clear for potential users. Users are normally not very familiar with sampling statistics and thus the results should not require a Ph.D. in statistics for any immediate and basic interpretation. Users will have confidence only in information that they can understand. The inventory design should be documented and give advice for the impartial interpretation of data. As sample-based results are always subject to sampling errors, it is necessary to accompany any statistical estimate with estimates of sampling error or confidence interval.
7. Forest inventories should “only” present information in statistical and mapped format. It is beyond the mandate of a forest inventory to interpret results. However, forest inventory specialists should give advice for the interpretation of data. This restraint is also intended as a safeguard for the integrity of the inventory process.
8. In inventories on successive occasions, terms and definitions should not be changed unless it can be argued that the benefits outweigh the problems introduced by a change. When terms and definitions are changed between assessments one cannot distinguish between true change and change due to change in definitions.
9. Planning of a forest inventory is a complex task that involves expertise from many fields; thus, experts from silviculture, forest management planning, economics, policy, ecology, or timber products need to be consulted at an early stage.

1.2 Objectives

The main elements of an inventory depend very much upon the inventory objective; thus the objectives of an inventory have to be laid down in a very early phase of inventory planning. The exact definition is a joint action by the inventory designer and the potential user group. It is a very laborious

undertaking and consequently too little effort is often committed; yet without it, one may lose sight of the real objectives with the risk of accepting inappropriate methods and procedures. The formulation of the objectives constitutes not only the basis for the design of the sampling methods but also an instrument for checking success once the survey is complete.

Four specific guidelines should be considered when determining inventory objectives (FAO 1998):

1. Objectives need to be determined jointly by the people who will use the results, including forest managers, planners, and decision-makers, as well as by inventory specialists. Inventory objectives should not be determined by inventory specialists alone.
2. Not all inventory objectives have the same level of importance. Some have higher priority than others and it is the objectives having highest priority that should determine the inventory design and the presentation of results.
3. Inventory objectives should reflect the physical effort that will be required to conduct an inventory, the organization, estimated costs and time, the existing knowledge of resources, the availability of specific aspects of inventory technologies, and institutional capability. All have a direct bearing upon the implementation of an inventory. An overriding consideration is that an inventory must be practicable and achievable. The value of an incomplete inventory that lacks important information and thus limits the possibility to establish causal relationships could be zero or close to zero.
4. All objectives should be *SMART*
 - Specific
 - Well defined.
 - They are clear to anyone who has a basic knowledge of the project.
 - Measurable: They provide quantifiable measures of achievement and variance from set objectives.
 - Agreed upon: There is agreement between the users and the project team on what the objectives should be.
 - Realistic: Looking at the resources, knowledge, and time available, can the objective be accomplished?
 - Time-framed
 - How much time is needed to accomplish the objective?
 - Having too much time can affect the project performance.

The information requirements from forest owners, policy planners, the scientific community, and society in general concerning forest resources have been growing steadily since the 1950s when the main focus was on information about timber supply (Table 1.1). The multiple functions of forests, biomass,

Table 1.1. Increase in information needs about forest lands in the USA (after Lund and Smith 1997)

					Nonforest lands, habitats, old growth and primary forests
				Ecosystems, biodiversity, NWGS	Ecosystems, biodiversity, NWGS
			Global warming	Global warming	Global warming
	Multiple resources	Biomass Multiple resources	Biomass Multiple resources	Biomass Multiple resources	Biomass Multiple resources
Timber 1950s	Timber 1960s	Timber 1970s	Timber 1980s	Timber 1990s	Timber 2000+

NWGS nonwood goods and services

global warming, biodiversity, and nonwood goods and services have since gained prominence (Lund and Smith 1997).

The thematic scope of forest inventories can vary considerably. It is advisable to review global initiatives and obligations in order to get a broad view on potential information topics to be covered by a forest inventory. UNCED criteria and indicators for sustainable forest management have been formulated through several international, national, and nongovernmental processes. These include the Pan-European (or Helsinki) process (for European forests), the Montreal Process (for temperate and boreal forests), the Tarapoto Proposal of Criteria and Indicators for Sustainability of the Amazon Forest, the United Nations Environment Program (UNEP)/Food and Agriculture Organization (FAO) Expert Meeting on Criteria and Indicators for Sustainable Forest Management in Dry-Zone Africa, or the Lepaterique Process of Central America. The ITTO, the Tarapoto Process (TARA), the Center for International Forestry Research (CIFOR), the African Timber Organization (ATO), and the Central American Commission for Environment and Development (CCAD) developed systems of criteria and indicators for sustainable forest management which cover administrative, economic, legal, social, technical, and scientific issues which affect natural forests and plantations. The criteria define the essential factors of forest management against which forest sustainability may be assessed. Each criterion relates to a key management factor which may be described by one or more qualitative, quantitative, or descriptive indicators. Through measurement and monitoring of selected indicators, the effects of forest management action, or inaction, can be assessed and evaluated and action adjusted to ensure that forest management objectives are more likely to be achieved. Table 1.2 summarizes the criteria

Table 1.2. Criteria and indicators for sustainable management (after FAO 1998)

1. Extent of forest resources and global carbon cycles	
	Area of forest cover
	Wood-growing stock
	Successional stage
	Age structure
	Rate of conversion of forest to other use
2. Forest ecosystem health and vitality external influence	
	Deposition of air pollutants
	Damage by wind erosion
	Forest vitality indicators
	Incidence of defoliators
	Reproductive health
	Forest influence indicators
	Insect/disease damage
	Fire and storm damage
	Wild-animal damage
	Anthropogenic influence indicators
	Competition from introduction of nonnative plants
	Nutrient balance and acidity
	Trends in crop yields
3. Biological diversity in forest ecosystem	
	Ecosystem indicators
	Distribution of forest ecosystems
	Extent of protected areas
	Habitat suitability
	Forest fragmentation
	Area cleared annually of endemic species
	Area and percentage of forest lands with fundamental ecological changes
	Forest fire control and prevention measures
	Species indicators
	Number of forest-dependent species
	Number of forest-dependent species at risk
	Reliance on natural regeneration
	Resources exploitation systems used
	Measures for in situ conservation of species at risk
	Genetic indicators
	Number of forest-dependent species with reduced range
4. Productive functions of forests	
	Percentage of forests/other wooded lands managed according to management plans
	Growing stock
	Wood production
	Production of nonwood forest products
	Annual balance between growth and removal of wood products
	Level of diversification of sustainable forest production
	Degree of utilization of environmentally friendly technologies

Table 1.2. (continued)

5. Protective functions of forests
Soil conditions
Water conditions
Management for soil protection
Watershed management
Areas managed for scenic and amenity purposes
Areas and percentage of forest lands managed for environmental protection
Infrastructure density by FMU category
6. Socioeconomic functions and conditions
Indicators for economic benefits
Value of wood products
Value of nonwood products
Value from primary and secondary industries
Value from biomass energy
Economic profitability of SFM
Efficiency and competitiveness of forest products production, processing, and diversification
Degree of private and nonprivate involvement in SFM
Local community information and reference mechanisms in SFM
Indicators for the distribution of benefits
Employment generation/conditions
Recreation and tourism
Forest-dependent communities
Impact on the economic use of forests on the availability of forests for local people
Quality of life of local populations
Average per capita income in different forest sector activities
Gender-focused participation rate in SFM
7. Political, legal, and institutional framework
Legal framework that ensures participation by local governments and private landowners
Technical and regulatory standards of management plans
Cadastral updating of the FMU
Percentage of investment on forest management for forest research
Rate of investment on the FMU level activities: regeneration, protection, etc.
Technical, human, and financial resources

FMU forest management unit, SFM sustainable forest management

and indicators identified by the processes and initiatives and should facilitate the definition of inventory objectives.

As not all objectives have the same importance, the priority of inventory objectives has to be assessed before designing the inventory. Before a final decision on the inventory objectives, all issues that could constrain an implementation of the inventory should be listed and considered. Issues include cost

limits, availability of staff, presentation of the findings, the schedule, or the population for which estimates should be given.

The listing of inventory objectives should not be confused with the list of attributes to be assessed. Based on the objectives, the attributes for field assessments, remote-sensing imagery, or other data sources have to be derived. The attributes have to be defined in detail on the basis of data type, desired error, and units of reference.

1. *Populations for which estimates are to be presented.* The term population is used to describe that aggregate from which the samples are to be taken and for which valid conclusions are to be drawn. In forest inventories it can be relatively difficult to define the population, as the exact borders and the surface area of the region to be surveyed must first be determined. Here, maps, land-use classification, and remote-sensing imagery can be of great assistance.
2. *Data type.* For each type of information required the measurement scale must be defined. The results may be presented in one of three ways:
 - (a) Graphically – through maps, charts, diagrams, etc.
 - (b) Descriptively, or qualitatively – for example, forest type, stage of development
 - (c) Quantitatively – for example, stem count, total standing volume, or mean increment

The simplest method of measurement is to group observations into qualitative classes. Here, a general system of classification is based on given characteristics and takes only the major manifestations of these into consideration.

The allocation of data into different classes of equal standing is termed nominal scaling as opposed to ordinal scaling, which reveals a ranked order. Nominal scaling may, for instance, involve classification according to tree species, administrative unit, or soil type. Examples of ordinal scaling are the stand tree development class, or the stem quality class. Mathematical operations for nominal as well as ordinal scales are limited.

Where quantitative data are to be furnished, any given parameter (i.e., population characteristic) is allocated a number reflecting the intensity of a certain characteristic. Where the measurements are linearly related to values and the zero point is arbitrarily set, we have an interval scaling. An example is the measurement of temperature: on the Fahrenheit scale the freezing point of water is 32°F, and water boils at 212°F (at standard pressure); on the Celsius scale the equivalent temperatures are 0 and 100°C, respectively. Interval scaling allows conclusions about the differences between observations made at different scales.

A further system for scaling quantitative data is the ratio or relative scaling. Here, a true zero point exists, and the relationships between numerical measurements can be directly interpreted as the relationship between the dimensions of objects. For instance, a tree 20-m tall is twice as tall as one only 10-m tall. Such a statement cannot be made for two temperatures. Examples in which relative scaling can be applied are weight, length, and time.

Whenever quantitative data are considered, it must be specified whether overall values (e.g., total standing crop of the inventory area) or ratios (per tree, unit area, or other units of reference) are to be given.

3. *Error Limits.* The results of any sampling survey are always subject to a certain degree of uncertainty, as only part of the population is measured and the measurements themselves may be subject to error. The uncertainty can be reduced through a careful choice of sampling strategy (design and estimators), taking more measurements, or employing better instruments. Most improvements impose additional costs. Consequently, it is necessary to specify the degree of precision to which the results should attain.

In deciding the limits of error, the two components (1) sampling error and (2) bias must be taken into consideration just as much as the chosen significance level for confidence intervals. The desired error must be related to the population, be it the entire inventory area or only a part of it. The given population and the desired error strongly influence the intensity of the survey.

1.3

A Typology of Forest Inventories

Forest inventories can be differentiated according to combination and emphasis of different data categories, i.e., the inventory objectives and the size of the area to be surveyed.

Global forest inventories are conducted to determine forest resources at the global level. This usually means the compilation of results from separate national inventories. Thanks to advances in remote-sensing techniques, satellite data can now be used to determine the distribution of forest vegetation throughout the world (Itten et al. 1985; Kuswaha 1990; FAO 2003). Global inventories were conducted by the FAO in 1946, 1953, 1958, and 1963 (World Forest Inventory) and in 1990 and 2000 (Global Forest Resources Assessment). Much discussion and readjustment of the data catalogues from national inventories was necessary before the data could be compiled to give a global picture (UN-ECE/FAO 2000; FAO 2001).

Individually designed national inventories do not permit monitoring of either the environment or the development of resources on a global or continental scale. Joint or multinational coordinated surveys allow the collection of

data for large, cohesive areas, for instance, the UNEP/FAO Project on Monitoring Tropical Forest Cover or the annual UN Economic Commission for Europe International Cooperative Program (ECE-ICP) reports on forest condition in Europe, which began in the mid-1980s.

National forest inventories are already being conducted in many countries. In western Europe, almost every country has its own national inventory (EC 1997), some of which, especially those in Scandinavia, have been running for many years. Timber volume is usually employed as a key parameter, though information on the distribution of forested areas, the condition of the forest, and productivity is also collected (Lund et al. 1987; Lund 1998). The nonwood functions of the forest are receiving increased attention. Ideally, national inventories should be planned as permanent surveys and conducted by a specific organization with a permanent staff. Information obtained through national inventories is mainly applied in questions of national forest policy (Clement 1988; Lund 1998).

Land-use inventories record not only forest resources but also the distribution of other types of land use. Aerial photographs and satellite data are of especial importance here. The value of a forest inventory can be considerably increased by extending it to give a land-use inventory. Where noncommercial forms of vegetation, such as swamps, barren areas, or maquis, are recorded in addition to the various types of agricultural use, areas potentially suited for forestry can be identified. In Africa, FAO introduced an integrated system of nomenclature for agricultural and forest areas (AFRICOVER).¹

Regional inventories register only a part of the national forested area and usually cover some hundreds of thousands up to two million hectares. Similarly to national inventories, they are intended to provide a general picture of the situation regarding forestry (Pellico-Netto 1979).

Reconnaissance inventories aim at furnishing a rough outline of the forest conditions. As well as the location and extent of forested areas, they may aim to register access, species composition, tree dimensions, the distribution of various forest types, and a crude assessment of timber quality (Touber et al. 1989). Through the employment of aerial photography and the restriction of field surveys to the minimum, reconnaissance inventories can be conducted at little cost. They frequently serve the preparation of a more intensive forest inventory. Data on the degree of variation and time-and-motion studies conducted during a reconnaissance inventory facilitate the planning of the definitive inventory.

Exploitation surveys or logging plan surveys are conducted in forests to provide a basis for the planning of programs for timber harvesting. The main focus is on determining the standing crop, classified according to species, dimensions, and assortment, and describing the accessibility of the area concerned. Little or no attention is paid to increment or ecological conditions.

¹ <http://www.africover.org>

Where the economic potential of establishing a wood-processing industry is to be examined, a *forest industries feasibility study* (FIFS) is standard practice. A FIFS comprises the collection of data not only on the forest resources as such but also on the situation regarding demand and marketing, potential sites for processing plants, the job market, sources of water and power, transport possibilities, and existing industries. For further details see Higgins et al. (1973), Philip (1976), Lanly (1977) and Staepelaere and Ginsburger (1978). As the establishment of a timber industry is only worthwhile where there is a steady supply of raw material, it is necessary to determine the forest resources in considerably more detail than is usual in exploitation surveys. In particular, the sustained yield of exploitable timber must be computed.

Working plan surveys are the most intensive type of forest inventory. The preparation of working plans for intensively managed but restricted areas requires relatively detailed information. Usually the data are computed on a stand-by-stand basis for each species. Information on increment, detailed forest maps, data on the quality of the various sites are just as necessary as details on topography, ownership, and access.

Forest condition inventories report on the symptoms of diseases and stress (water, nutrient, competition, air pollution, climate change). In central Europe and North America forest condition surveys are conducted annually in order to track the course of development of different types of damage (UN-ECE 1998, 2004).

In addition to the types of inventories just described, special surveys are sometimes conducted, for instance, to determine regeneration, available biomass, or carbon sequestration.

Forest inventories may also be classified in terms of time. Static inventories may be conducted simply to determine conditions at a given point in time, and do not require consideration of possible subsequent inventories – a fact which considerably simplifies their planning. Nevertheless, the additional expense of permanently marking the sample plots is often a worthwhile investment.

The various types of inventory are not distinct types. In practice they will often overlap. Neither is their nomenclature static; increasing demands on the forest and forest information will invariably stimulate the development of new types of inventory.

1.4 Inventory Planning

Lund (1998) outlined the steps needed to develop and implement a forest inventory (Fig. 1.1). As the planning of an inventory may take a long time, usually involves experts in different fields, and requires networking between different tasks, it is advisable to base the entire inventory on a sound project

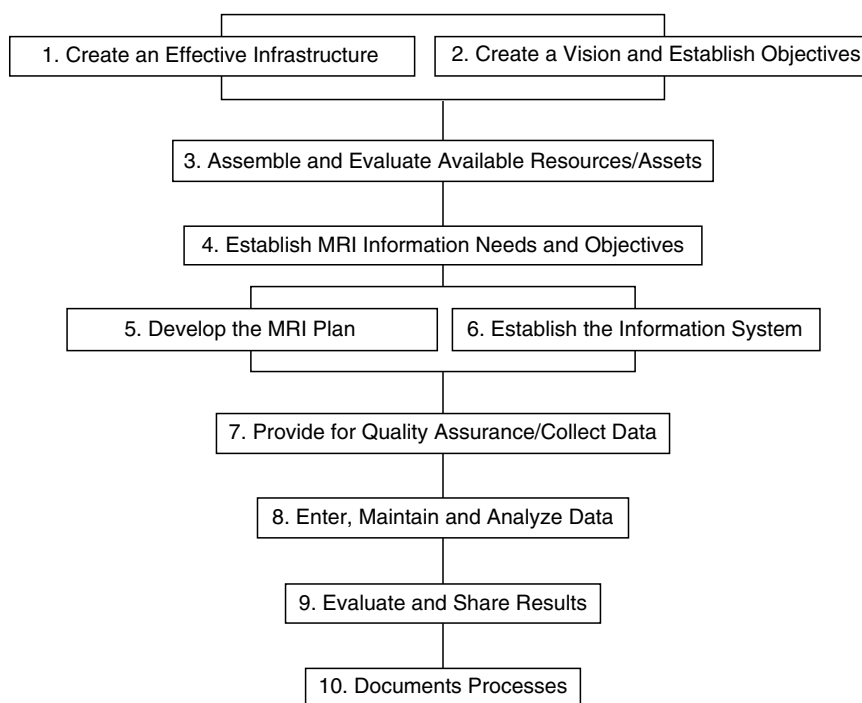


Fig. 1.1. Steps in implementing a forest inventory (after Lund 1998)

management concept (Burke 2003). Good project management deals with three factors: time, cost, and performance. Projects are successful if they are completed on time, within budget, and meet performance requirements. A multitude of components in any large project needs to be controlled. A large toolkit of techniques, methodologies, and tools has been developed for this purpose. They provide the tools for managing different components involved in a project: planning and scheduling, developing a product, managing financial and capital resources, and monitoring progress. However, the success of a project will always rest on the abilities of a project manager and the team members. A project life cycle includes the four phases (1) study phase, (2) design phase, (3) development phase, and (4) operation phase.

The following overview presents the separate steps in the four project management phases and is intended to serve as a checklist for inventory planning:

1. Study phase
 - (a) User needs.
 - (b) Initial investigation.

- (c) Formulation of the inventory objectives:
 - Necessity of the inventory, information needed.
 - Potential users of the results.
 - Formulation of the inventory objectives.
 - Priorities of the objectives.
 - (d) Determination of the administrative and logistic situation:
 - Bodies responsible for the execution.
 - Budget (available funds, bodies providing funds, financial administration, time available).
 - Legal basis (right of access to privately owned forest, labor laws, protection of private forest owners from information leaks).
 - Available information (maps, aerial photographs, data from previous forest inventories and other types of survey, scientific studies in the inventory area, general details on the forest. Data on variation, description of the terrain, accessibility, and climatic conditions).
 - Potential use of aerial photography and remote sensing imagery.
 - Possibilities for recruiting qualified staff.
 - Available equipment (vehicles, computers and software, measuring instruments, tents).
 - Responsible bodies (staff management, financial administration, monitoring of data security, data release, dissemination of data, definition of inventory objectives and methods, execution of field surveys, data evaluation, formulation and release of the final results, publication, additional analyses).
 - (e) User review.
 - (f) Study phase report.
2. Design phase
- (a) General system review
 - (b) Compilation of the data catalogue and stipulations for measurements
 - Listing of all variables to be analyzed (depending on inventory objectives)
 - Definition of qualitative data
 - Instructions for measurement of quantitative data
 - (c) Inventory design
 - Description of the design to be employed
 - Sampling methods
 - Description of the sampling units, especially their form, size, number, and distribution
 - Computation of the necessary sample size for each inventory level, survey intensity
 - Description of inventory levels (aerial photographic survey, interpretation of satellite data, field surveys, questionnaires)

- Map construction
- Estimation of areas
- Description of statistical methods for evaluation, estimation procedures, correlations to be applied, and the computed parameters
- Methods of volume determination (e.g., volume functions, points of measurement on the tree, volume inside or outside bark)
- Determination of regeneration conditions
- Determination of timber quality
- Description of road and transport networks
- (d) Data base and/or information system design
- (e) Control requirements
- (f) Software selection
- (g) Equipment selection/acquisition
- (h) Staff recruitment
- (i) Field manual
- (j) Plans for work progress
- (k) Design phase report
- 3. Development phase
 - (a) Implementation planning
 - (b) Computer program design
 - (c) User review
 - (d) Equipment acquisition and installation
 - (e) Field tests/pilot survey
 - (f) Computer program testing
 - (g) System testing
 - (h) Reference manual preparation
 - (i) Personnel training
 - (j) Changeover plan preparation
 - (k) Development phase report preparation
 - (l) User acceptance review
- 4. Operation phase
 - (a) Interpretation of aerial photographs and/or remote sensing data
 - Instruments (interpretation instruments, computers, software)
 - Organizations, staff, competence, duties
 - Documentation and backup of the results
 - (b) Field surveys
 - Organization, central coordination
 - Communication between field survey teams and central coordinators
 - Recording and delivery of data
 - Training of field staff (localization of sample plot centers, assessments on sample plots, use of instruments)
 - Check cruises

- (c) Data evaluation
 - Digitalization of data
 - Checking and correction of data
 - Data analysis
 - Operating, system management, data security
- (d) Final report
 - Preparation (output format printed, Web-based, or CD-ROM)
 - Approval for release
 - Reproduction.
 - Dissemination
- (e) Performance evaluation